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(54) Measuring components of force and moment

(57) A device for measuring components of force (*Fx, Fy, Fz*) and torque (*Mx, My, Mz*) along and about three orthogonal axes, comprises a central hub portion (23) an annular rim portion (24) and four radial spoke portions connecting the hub and rim portions and carrying strain gauges (51—82) each spoke portion including a radially inner section and an outer section of reduced width compared with the inner section to increase the flexibility of the spoke portions under moments applied about the longitudinal directions thereof.

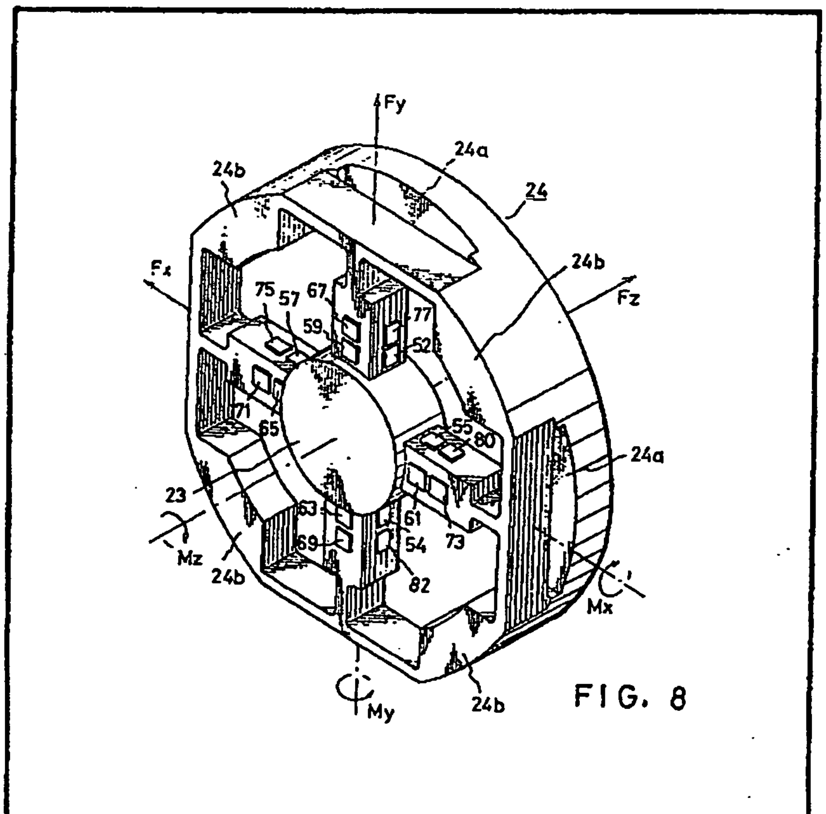

FIG. 8

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SPECIFICATION

Devic for measuring components of force and moment in plural directi ns

This invention relates to a device for measuring components of force and moment in plural directions, especially to a device for measuring such components along and about three orthogonal axes. The device may be used in a tire tester, wind tunnel balance, and the like.

Various devices and equipments have been proposed for measuring an applied force as its components in predetermined plural directions. Typical examples of such device are disclosed in the registered Japanese patent No. 775,978 and the opened Japanese patent specification No. 52-133270 (Patent application No. 51-50625), which are cited herein as the references. As shown in these references, the device is composed generally of a central hub portion, a circular rim portion and four radial spoke portions connecting the hub and rim portions and having suitable strain gauges adhered thereon. When one of the hub and rim portions is fixed and a force is applied to the other, various strains will occur in the spoke portions to change the resistances of the respective strain gauges. Therefore, if the strain gauges are appropriately connected in a circuit, the strains and corresponding components of force can be detected in the directions of the spokes.

However, the such prior art devices have such disadvantages that it is very difficult to measure a twisting moment applied to a specific spoke portion due to interference of deflections of the other portions, and that the device must become much complicated and costly if one intends to overcome this trouble, as described in more detail later.

Accordingly, an object of this invention is to provide an improved structure of this type of measuring device, which is simple and easy for manufacture and enables measurement of the components of force and moment in the respective directions individually without interference of the other portions.

In accordance with the invention there is provided a device for measuring components of force and moment in plural directions, comprising a central hub portion, a rigid annular rim portion, four spoke portions extending radially outwardly from said hub portion in mutually orthogonal directions, four chord portions coupled medially to the outer ends of the spoke portions to extend laterally thereof and coupled at their ends to said rim portion, said chord portions exhibiting substantial flexibility under forces applied thereto in the directions of said spoke portions, coupled thereto, the cross section of each spoke portion being rectangular with on pair of opposed sides parallel to th axis of the hub portion, and each spoke portion including a radially inner section adjacent to said hub portion and an outer end section having a width between said opposed sides substantially less than that of said inner section whereby said outer end section exhibits substantial flexibility under twisting forces applied about the radial direction of said spok portion, and strain sensing elements mounted on the four surfaces of the inner section of each spoke portion. During force measurements, one of hub and rim portions is fixed and a force is applied to the other. Four spoke portions extend outwards from the hub portion to mutually orthogonal radial directions and the each spoke portion has a rectangular cross-section with its width parallel to the radial plane and its height perpendicular to the radial plane. A chord member is coupled laterally at its midway to the top of the each spoke portion and also coupled at the both ends to the rim portion. The chord member is designed to exhibit substantial flexibility with respect to a bending force in the extending direction of the corresponding spoke portion. In order to detect mechanical strains appearing in the each spoke portion, a plurality of mechano-electric transducer elements are adhered onto the surfaces of the spoke portion.

According to a feature of this invention, the each spoke portion consists of a trunk section adjacent to the hub portion and an end section adjacent to the chord member and the width of the cross-section of the end section is significantly less than that of the trunk section so that the end section exhibits substantial flexibility with respect to a twisting force about the extending direction of the spoke portion. The transducer elements are adhered onto the four surfaces of the trunk section.

A full understanding of the invention will be had from the following detailed description given with reference to the accompanying drawings, in which

Figure 1 is a front view representing an example of the prior art devices;

Figure 2 is a sectional view taken along a line II—II of Figure 1, representing exaggeratedly a state of deformation under a moment about the X-axis;

Figure 3 is a perspective view representing another example of the prior art devices;

Figure 4 is a front view representing an embodiment of the device according to this invention;

Figure 5 is a partial front view of the device of Figure 4 given for an aid of explaining its operation;

Figures 6 and 7 are partial front and back views of the device of Figure 4 representing locations of mechano-electric transducer elements adhered to the spoke portions thereof;

Figure 8 is a perspective view representing the device of Figure 4;

Figures 9*a* through 9*f* are circuit diagrams representing component force and moment measuring bridges according to this invention; and

Figure 10 is a front view representing another embodiment of the device according to this invention.

Throughout the drawings, same reference numerals are given to corresponding structural components.

A typical example of the prior art devices, which is disclosed in the aforementioned Japanese patent No. 775, 978, is shown in Figure 1. As shown in the drawing, it comprises a central hub portion 1, four spoke portions 2, 3, 4 and 5 extending outwards from the hub portion 1, a rigid annular rim portion 10 and four chord members 6, 7, 8 and 9 coupled laterally to their midway to the tops of the spoke portions 2, 3, 4 and 5, respectively, and also coupled at the both ends to the rim portion. These portions and members are preferably made in an integral body. Mechano-electric transducer elements, such as strain gauges, G1, G2, ... G8 are adhered to the both side faces of the spoke portions 2, 3, 4 and 5, respectively, which senses tension and compression applied thereto as a change of electric resistance.

Taking now the X-axis in the extending direction of the spokes 2 and 3 and the Y-axis in the direction of the spokes 4 and 5, the Z-axis is perpendicular to the plane of paper, as shown in the drawing. When the rim portion 10 is fixed and a force is applied to the hub portion 1 along the X-axis, the spoke portions 2 and 3 are subject to tension and compression and the spoke portions 4 and 5 are subject to bending. However, the X-ward dimension or thickness of the chord members 6 and 7 is made significantly less than the Z-ward dimension or width so that the members 6 and 7 are sufficiently flexible with respect to the X-ward force. Therefore, this force applied to the hub portion 1 is almost spent as the bending force for the spoke portions 4 and 5 and can be sensed by the strain gauges G5, G6, G7 and G8. As same as the chord members 6 and 7, the chord members 8 and 9 have thickness significantly less than widths and are sufficiently flexible in the Y-direction. This results in the bending mode of the spoke portions 4 and 5 approximating to "cantilever" mode. Similarly, a force applied to the hub portion 1 along the Y-axis can be measured by means of the strain gauges G1, G2, G3 and G4. Thus, in general, the components of force in the X and Y directions can be measured without interference of the components of force in the Y and X directions, respectively, by this prior art device.

However, this device may suffer from a significant trouble when a moment about the X and/or Y axis is applied to the hub portion 1. For example, as shown exaggeratedly in Figure 2, the moment *Mx* about the X-axis will cause twisting of the spoke portions 2 and 3, as well as Z-ward bending of the spoke portions 4 and 5. Various stress and strains appearing in the spoke portions interfere mutually due to rigidity of th spoke portions and it is substantially impossible to measure the moment *Mx* by the method of sensing bending strains as described above.

Th device of th abovementioned opened Japanese patent specification No. 52-133270 was proposed to overcome this trouble. The general structure of this device is shown in Figure 3. As understood from the drawing, a number of flexture portions are provided for removing interference of the twisting force to the bending strain to enable measurement of the components of moment, as well as the components of force, about the three axes X, Y and Z individually by means of strain gauges G as shown. However, as readily anticipated from the drawing, this device is so complicated in structure that it is very difficult to manufacture and, therefore, relatively high in cost.

Next, an embodiment of the device according to this invention will be described with reference to the drawings of Figures 4 through 8. As shown in Figure 4, the device of this invention comprises a central hub portion 23, a rigid annular rim portion 24, four radial spoke portions 25, 26, 27 and 28 and four chord members 19, 20, 21 and 22 coupled respectively at their midways to the spoke portions and the both ends to the rim portion, as same as in the prior art of Figure 1. However, in this inventive device, the spoke portions 25, 26, 27 and 28 are composed of trunk sections 11, 12, 13 and 14 and end sections 15, 16, 17 and 18, respectively, and the each end section has a "width" dimension less than that of the corresponding trunk section, while the both sections are substantially same in the thickness dimension, in the Z direction. The "width" of the each end section of spoke portion is sufficiently small to make it flexible with respect to the twisting force about the extending direction of the spoke portion.

As shown more clearly in Figure 8, the rim portion 24 includes four relatively thin base portions 24*a* and four relatively thick boss portions 24*b* extending forwards along the Z-direction. The chord members 19, 20, 21 and 22 are bridged between the respective boss portions 24*b* with some clearance with respect to the base portions 24*a*. Of course, the shape of the rim portion 24 of the inventive device may be similar to that of the prior art device of Figure 1, as shown in Figure 10. However, it should be understood that the structure of Figures 4 and 8 has an advantage of reduced overall diameter of the device over the structure of Figure 10.

As shown in Figure 5 as an example, when the rim portion 24 is fixed and a force is applied to the hub portion 23, the chord member 19 is liable to deflect in the α-direction under the X-component of force *Fx* and to twist in the β-direction under the Z-component of force *Fz* and the end section 15 of the spoke portion 25 is liable to twist in the γ-direction under the X-component of moment *Mx*, due to their reduced "width" dimensions as compared with their thickness dimensions, as previously mentioned. Accordingly, measurements of *Fx* and *Mx* are subject to almost no effect of the rigid trunk sections 11 and 12 of the spoke portions 25 and 26. As this is the case in the each quadrant of the device, it is concluded that the X-components of force and moment *Fx*

and *Mx* appear as bending strains in th spoke portions 27 and 28, the Y-components *Fy* and *My* appear as bending strains in the spoke portions 25 and 26 and the Z-components *Fz* and *Mz* appear as bending strains in the all spoke portions 25 to 28. In order to sense these bending strains to measure the components of force and moment, strain gauges 51 through 82 are adhered to the trunk sections of the respective spoke portions 25, 26, 27 and 28, as shown in Figures 6 and 7. Although the strain gauges in this embodiment are of the type, such as wire strain gauge or semiconductor strain gauge, which senses strains of the surface as a change of its electric resistance, other type of mechano-electric conversion elements, such as piezoelectric elements may be utilized.

As shown in Figures 6 and 7, each of the four surfaces of the trunk section of the each spoke portion carries two strain gauges arranged longitudinally thereon and the each spoke portion includes eight strain gauges in total. These strain gauges are connected in separate six bridge circuits as shown in Figures 9*a* through 9*f*. The strain gauges 51 to 66 in the three bridges of Figures 9*a*, 9*b* and 9*c* belong to a first group adjacent to the hub portion 23, while the other gauges 67 to 82 in the three bridges of Figures 9*d*, 9*e* and 9*f* belong to a second group remote from the hub portion. Although, in the following description, the first and second groups are shown to be used for measuring the components of force *Fx*, *Fy* and *Fz* and the components of moment *Mx*, *My* and *Mz*, respectively, other connections can be considered easily by those skilled in the art. In the each bridge circuit, a constant voltage is applied across terminals P from a voltage source B and a voltage change across junctions Q is measured by a voltmeter V.

As aforementioned, the component of force *Fx* appears as strains in the spoke portions 28 and 27, which are caused by co-sense X-ward bendings of these spoke portions and sensed by the strain gauges 51, 52, 53 and 54 on the both side surfaces thereof. In this case, the strain gauges 51 and 53 exhibit resistance changes opposite in polarity to the strain gauges 52 and 54, respectively. It can be understood that the connection of Figure 9*a* has been made in differential mode for obtaining a greatest change of voltage across the junctions Q. Similarly, the component of force *Fy* is measured by means of the strain gauges 55, 56, 57 and 58 on the both side surfaces of the spoke portions 26 and 25 through the bridge circuit of Figure 9*b*. The component of force Fz appears as strains in the all spoke portions, which are caused by co-sense Z-ward bending of these spoke portions and, therefore, sensed by the strain gauges 59 to 66 on the front and rear surfaces of them, through th bridge circuit of Figure 9*c*. It is also understood that this bridge is constructed also to btain a greatest voltage change at th voltmeter V.

On the other hand, the component of moment *Mx* appears as strains in the spoke portions 27 and 28, which are caused by counter-sense Z-ward bendings of these spoke portions and sensed by the strain gauges 67, 68, 69 and 70 on the front and rear surfaces thereof. In this case, the strain gauges 67 and 70 exhibit resistance changes opposite in polarity to the strain gauges 68 and 69, respectively. Therefore, the bridge connection of Figure 9*d* can provide a greatest voltage change at the voltmeter V. Similarly, the component of moment *My* is measured by means of the strain gauges 71, 72, 73 and 74 on the front and rear surfaces of the spoke portions 25 and 26 through the bridge circuit of Figure 9*e*. The component of moment *Mz* appears as strains in the cell spoke portions, which are caused by counter-sense Y-ward bendings of the spoke portions 25 and 26 and counter-sense X-ward bendings of the spoke portions 27 and 28 and sensed by the strain gauges 75 to 82 on the both side surfaces of the all spoke portions through the bridge circuit of Figure 9*f* which is also constructed to provide a greatest voltage change.

As understood from the above description, each of the strain gauges is used exclusively for measurement of each of the six components *Fx*, *Fy*, *Fz*, *Mx*, *My* and *Mz* but not common to two or more components. Moreover, these six components are measured respectively with the six separate bridge circuits as shown in Figures 9*a* through 9*f*. Accordingly, it is possible to measure any two or more components at the same time with no interference of the other components.

It should be understood that various modifications and changes can be made by those skilled in the art within the scope of this invention as defined in the appended claims. For example, the annular rim portion 24 may be square in shape, though it has been described to be generally circular.

Claims

1. A device for measuring components of force and moment in plural directions, comprising a central hub portion, a rigid annular rim portion, four spoke portions extending radially outwardly from said hub portion in mutually orthogonal directions, four chord portions coupled medially to the outer ends of the spoke portions to extend laterally thereof coupled at their ends to said rim portion, said chord portions exhibiting substantial flexibility under forces applied thereto in the directions of said spoke portions, coupled thereto, the cross-section of each spoke portion being rectangular with one pair of opposed sides parallel to the axis of the hub portion, and each spoke portion including a radially inner section adjacent to said hub portion and an outer end section having a width between said opposed sides substantially less than that of said inner section whereby said outer end section exhibits substantial flexibility under twisting forces applied about the radial direction of said spoke portion, and strain sensing elements mounted on the four

surfaces of the inner section of each spoke portion.

2. A device according to Claim 1, wherein said each spoke portion has eight strain sensing elements attached to the inner section thereof, four of said elements being used for measuring the components of linear forces and the other four of which are used for measuring the components of twisting moments.

3. A device according to Claim 1 or 2, wherein said hub portion, rim portion, spoke portions and chord portions are integral parts of a unitory member.

4. A device for measuring components of force and moment in plural directions, substantially as herein described with reference to Figures 4 to 9 of the accompanying drawings.

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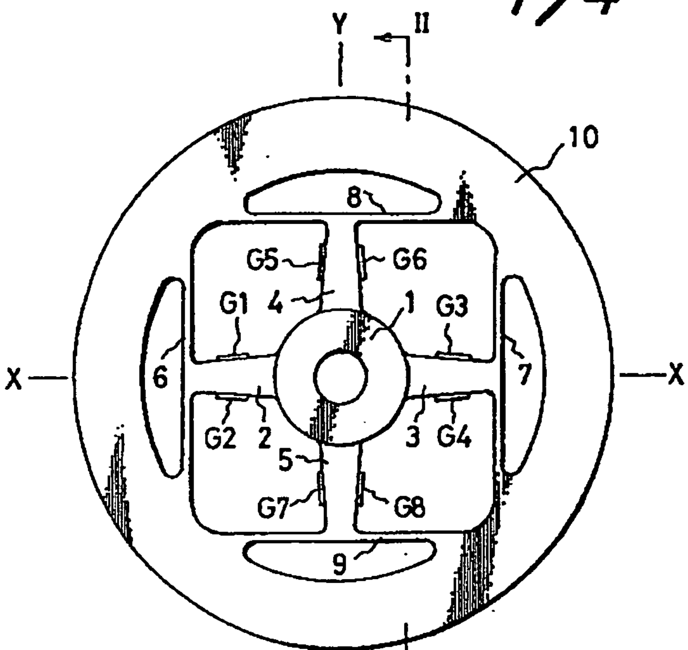

FIG. 1
(PRIOR ART)

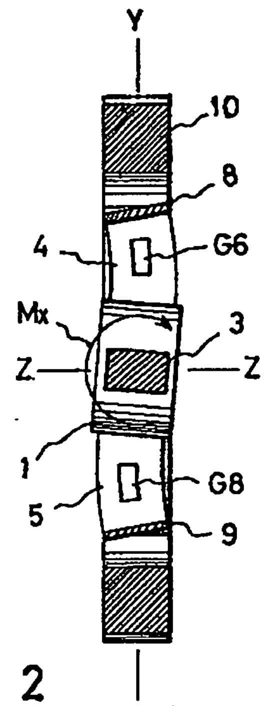

FIG. 2
(PRIOR ART)

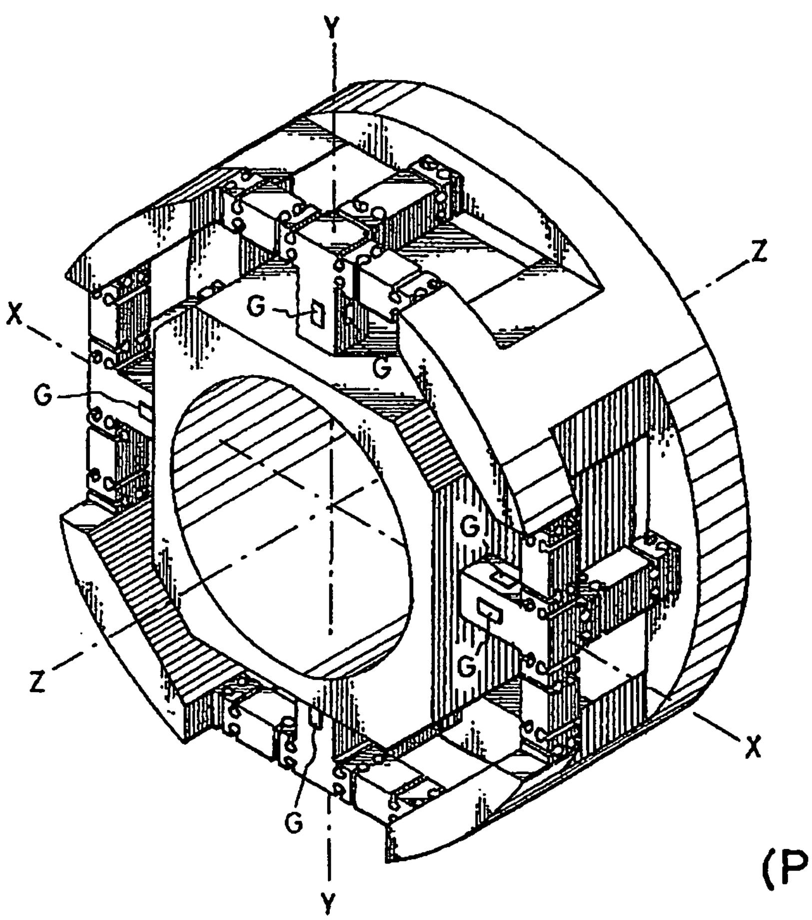

FIG. 3
(PRIOR ART)

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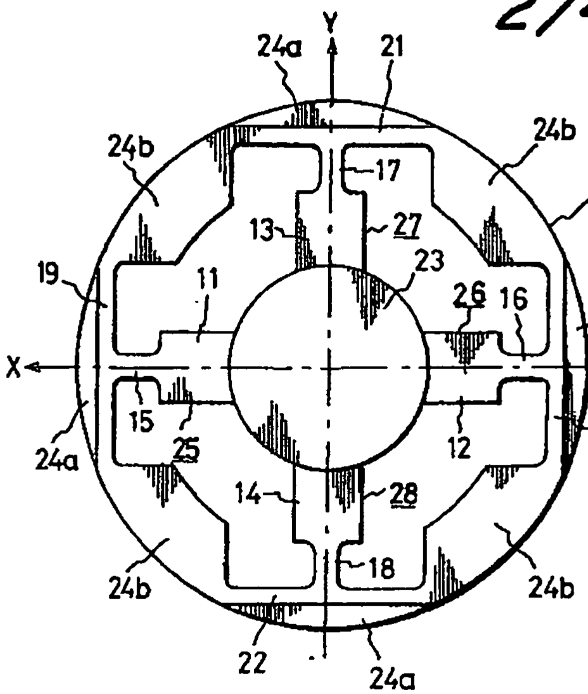

FIG. 4

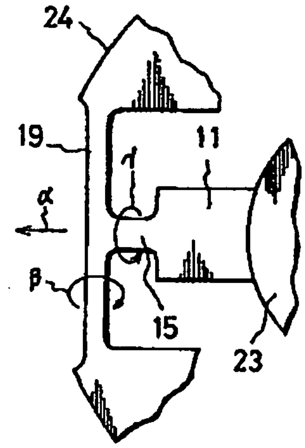

FIG. 5

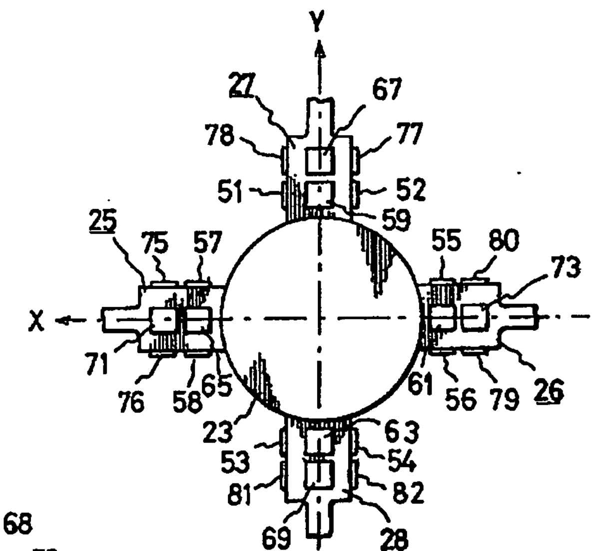

FIG. 6

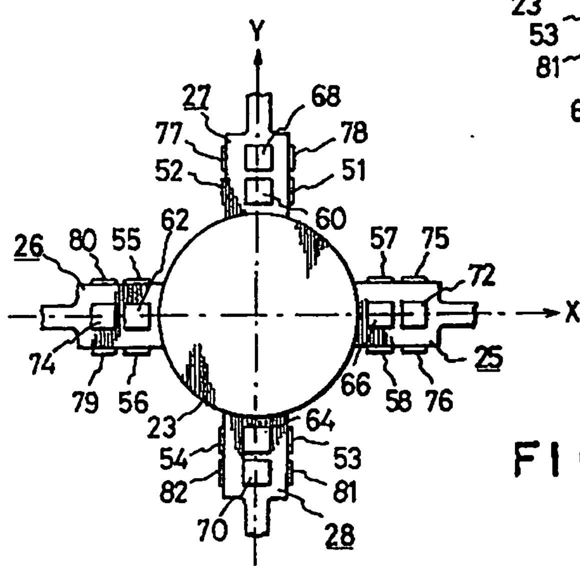

FIG. 7

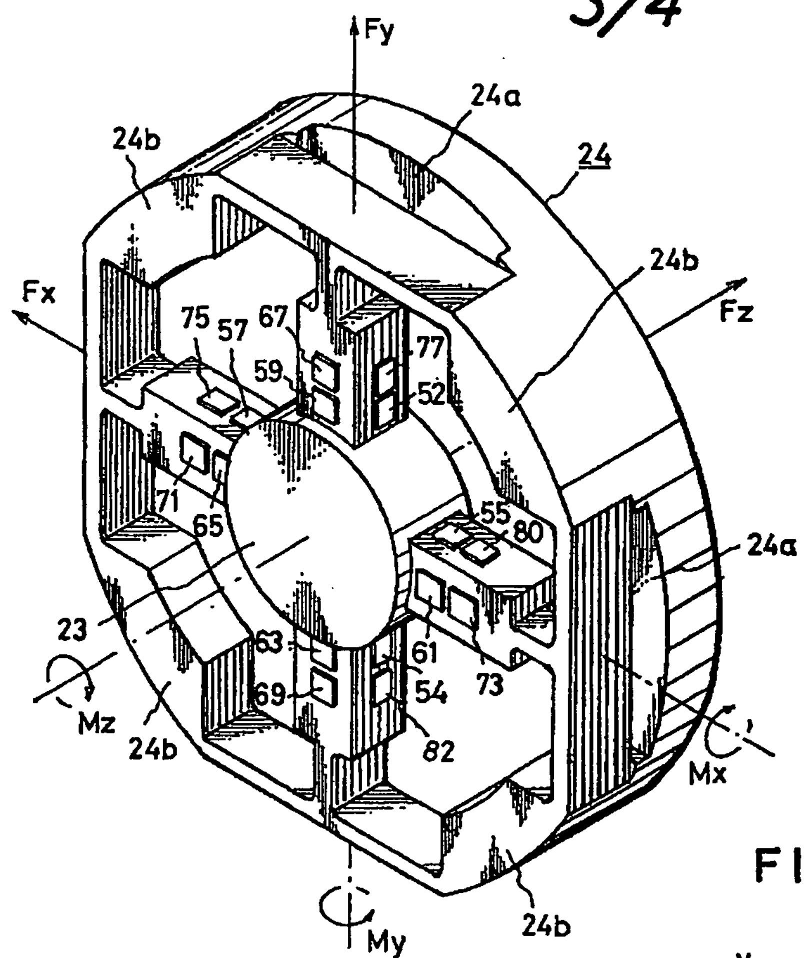
Fy
24a
24
24b
Fx
Fz
75
57
67
59
77
52
71
65
55
80
24a
23
63
61
73
69
54
82
Mz
24b
Mx
My
24b

FIG. 8

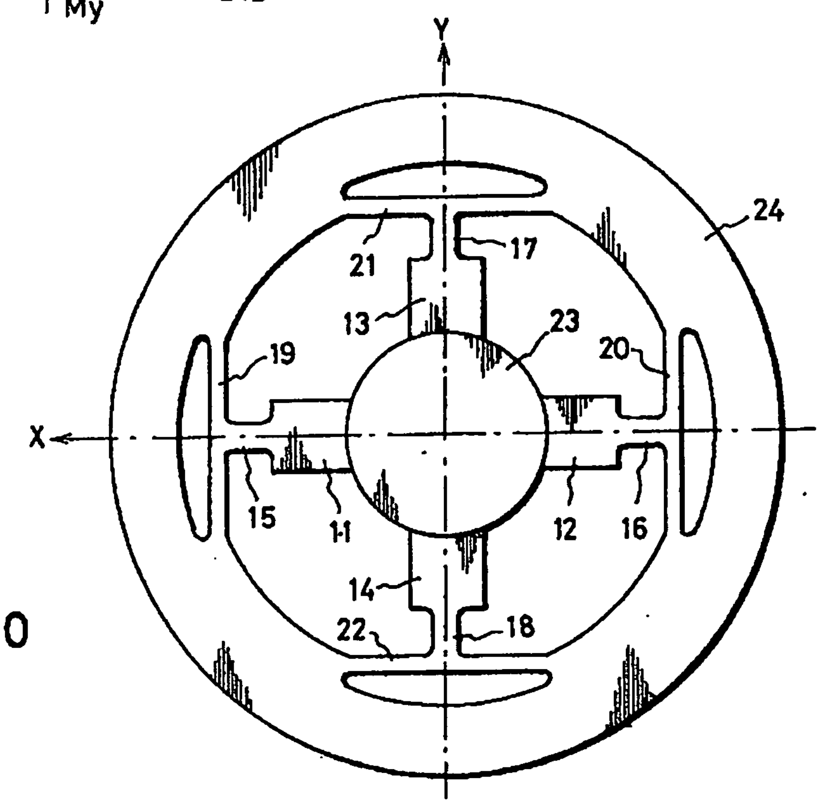
Y
24
21
17
13
23
19
20
X
15
11
12
16
14
22
18

FIG. 10

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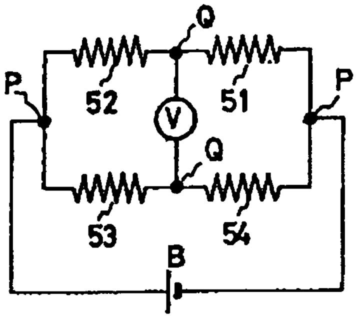

FIG. 9a

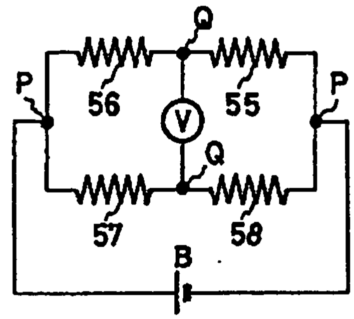

FIG. 9b

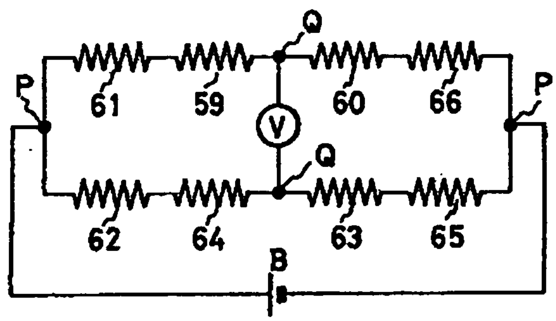

FIG. 9c

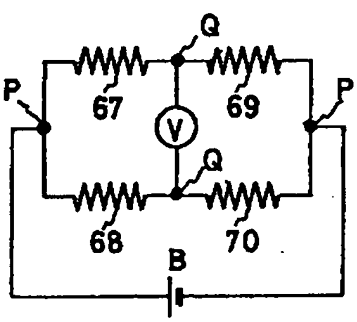

FIG. 9d

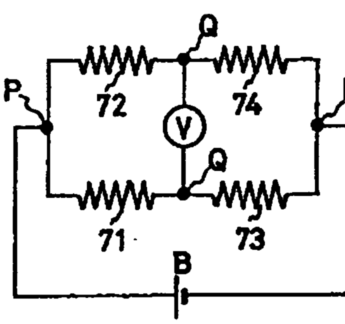

FIG. 9e

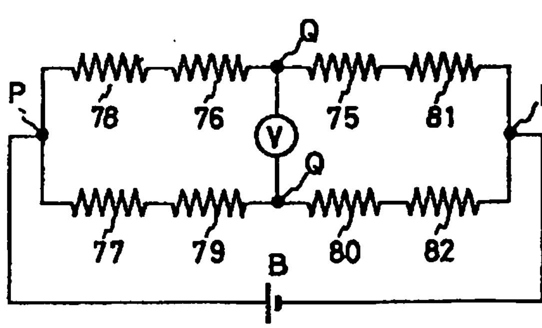

FIG. 9f